ERDA/JPL-954527-77/4
Distribution Category UC-63

(NASA-CR-157149) INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS. ENCAPSULATION TASK OF THE LOW-COST SILICON SOLAR ARRAY PROJECT Quarterly (Springborn Labs., Inc., G3/44 — N78-24636 — Unclas 20689

SIXTH QUARTERLY PROGRESS REPORT

Period Covered: August 12, 1977 - November 12, 1977

INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

JPL Contract 954527
Project 6072.1

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS 7-100 for the U. S. Energy Research and Development Administration, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

By

SPRINGBORN LABORATORIES, INC.
Formerly DeBell & Richardson, Inc.
Enfield, Connecticut 06082

November 1977

CONTENTS

LIST OF TABLES AND FIGURES

CONTENTS - Continued - 2

1. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (LSSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

During the past year materials for study were chosen on the basis of existing knowledge of generic chemical types having high resistance to environmental weathering. The materials varied from rubbers to thermoplastics and presented a broad range of mechanical properties and processing requirements. Basic physical and optical properties were measured on the polymers and were redetermined after exposure to indoor artificial accelerated aging conditions covering four time periods. Strengths and weaknesses of the various materials were revealed and data was accumulated for the eventual development of predictive aging methodologies.

Although most of the initially selected materials will not in themselves be recommended as encapsulants, studies of their properties have been useful in determining trends in materials and processing requirements.

During this quarter, flat-plate solar collector systems were considered and six basic construction elements were identified: outer coatings, superstrates, pottants, substrates, undercoats, and adhesives. Materials surveys were then initiated to discover either generic classes or/and specific products to function as each construction element. Cost data included in the surveys permit ready evaluation of each material in terms of the LSSA 1982 and 1985 target costs (materials allocation for 1985 is $0.23 per square foot).

Silicones, fluorocarbons, glass, and acrylic polymers have the highest inherent weatherability of materials studied to date. Only acrylics, however, combine low cost, environmental resistance, and potential processability. This class will receive particular emphasis.

Low-cost coatings to screen out deleterious ultraviolet light were also investigated, with considerable success. One-mil coatings of acrylic resin containing UV absorbers were prepared in the laboratory and found to have zero percent ultraviolet transmittance in several cases. These coatings may permit the use of low-cost, UV-unstable materials as encapsulants.

The plasma-spray process of applying conformal coatings received further attention this quarter but still proved to be unsuccessful in laboratory trials on miniature modules.

2. INTRODUCTION

The goal of this program is to identify and evaluate materials and encapsulation processes for the protection of silicon solar cells for service in a terrestrial environment. Systems will be recommended, consistent with DOE objectives, for the 1982 requirements of $2.00 a watt and for the 1985 target of $0.50 per watt (23 cents per square foot materials allocation). Encapsulation packages are being designed to provide a minimum service life of at least 10 and preferably 20 years. Consideration is also being given to mass-production capabilities.

Assuming the flat-plate collector to be the most efficient design, nine different basic variations have been considered and six construction elements identified. These elements are (a) outer covers, (b) superstrate materials, (c) pottants, (d) substrates, (e) back covers, and (4) adhesives. At present, extensive surveys are being conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element. Properties being considered are cost, transparency, weatherability, and applicability processing.

An additional task is the investigation of ultraviolet light stabilizers, antioxidants, fillers, and other techniques to improve the weatherability and extend the environmental life of materials having low UV resistance. Through the use of these processes, otherwise unweatherable materials may become cost-effective candidates for the LSSA program.

Prototype cell modules have been encapsulated with combinations of materials exhibiting promising properties and are being exposed to both natural and artificial weathering conditions. It is anticipated that specific problems relating to encapsulation materials and processes will be identified in this study.

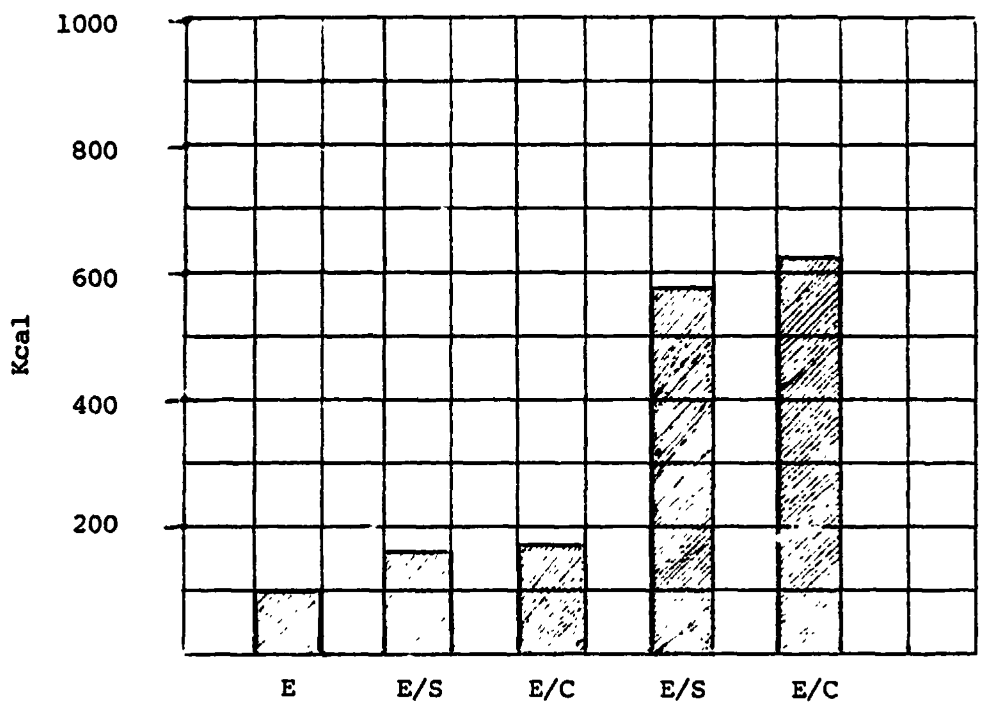
The testing program incorporates evaluation of initial properties of selected polymers and subsequent retesting after exposure to accelerated aging conditions. The aging environments consist of combinations of heat, humidity, and ultraviolet light, followed by testing of mechanical and optical properties. It is hoped that definitive correlations of natural and artificial aging techniques will result from this study and permit predictable accelerated materials testing to be conducted.

still may not have sufficiently low modulus to provide the required degree of stress relief from thermal expansion.

Although the use of plasma spray has not been overly successful for this phase of the encapsulation task, it may provide an economical way to apply coatings in various other areas of the LSSA project.

<u>FIGURE 1</u>

Energy Comparison



74 Kcal	127 Kcal	603 Kcal
Epoxy fusion alone	Epoxy plasma sprayed on steel and ceramic.	Epoxy fluid-bed coated on steel and ceramic.

Average energy difference: $\frac{476 \text{ Kcal}}{1883 \text{ Btu}} = 20\%$

Support Data for Figure 1

Material Constants	Epoxy	Steel	Ceramic
Size (ft^2x in.)	100 x 5 mils	100 x 1/4	100 x 1/4
Density (g/cm^3)	1.5	7.83	3.32
Weight (Kg)	1.77	28.2	11.95
Specific heat (cal/g)	0.25	0.11	0.27
Melting point (^oC)	190	-	-
ΔT (Temperature Difference)	167	167	167
$\Sigma\Delta$H (Total Heat) (Btu)	293	2056	2138
$\Sigma\Delta$H (Total Heat) (Kcal)	74	518	539

4. UV UPGRADE

Other than acrylics and fluorocarbons, plastics are not inherently resistant to weathering. This limitation does not mean that plastics cannot be modified for outdoor use, however. Weather-resistant coatings through internal compounding of special additives can adhieve dramatic improvements in environmental resistance.

Most of the adverse effects of weathering result from the ultraviolet portion of sunlight, generally in the range between 300 and 400 namometers. The energy contained in ultraviolet light can break the molecular chains in a polymer and promote oxidation, eventually resulting in loss of mechanical and other properties. Deterioration by weathering will depend on the material, the additives, the total amount of radiation absorbed, the temperature, humidity, and possibly other factors.

Protection from UV light is obtained with stabilizers known as ultraviolet inhibitors; and protection from oxidation is achieved with the use of antioxidants. Most frequently the two used together have a synergistic reaction in which the increase in weatherability is greater than that obtained with the use of either one alone. Antioxidants used alone - especially in large quantities - often accelerate UV-catalyzed degradation.

The most efficient form of stabilization involves the use of pigments which render the polymer opaque. Generally, the most effective means of improving the weather resistance of plastics is to compound them with carbon black. Carbon black is totally opaque to both visible and ultraviolet portions of the spectrum and additionally serves as a free-radical trap that inhibits chain scission. Zinc oxide is another UV-absorbing opaque pigment that is white in color and consequently heat and light reflective. Although the primary interest in LSSA at present is transparent potting compounds, the use of opaque additives will probably find application in the stabilization of substrate and undercoating materials.

Transparent materials are much more difficult to stabilize, requiring either appropriately select overcoatings and/or the correct blend of UV absorbers, antioxidants, and other stabilizers. Tables 1 and 2 list various common commercial UV stabilizers and antioxidants. UV stabilizers are typically used at 0.2-0.8 parts per hundred parts resin, and antioxidants at the 0.05 to 0.5 parts level. Upgrading by internal compounding has been demonstrated in previous studies (Fifth Quarterly Progress Report, August 1977) and found to be successful in retaining optical transparency of the four polymers exposed. Further information on the efficacy of this approach will be available when data are reported at the end of the eight-month exposure period.

During this report quarter, stabilizing films and coatings were investigated. Upon surveying present commercial sources, very few transparent UV-absorbing films were discovered. Acrylic or fluorocarbon films have been laminated commercially over thermoplastic sheet materials, with notable increases in weatherability. Korad acrylic film (Excel Corporation, Newark, New Jersey) is another example of this approach.

Only three domestic commercial ultraviolet-absorbing films were discovered: Tedlar UT (Du Pont, Wilmington, Delaware), Llumar (Martin Processing, Martinsburg, West Virginia), and a plasticized polyvinyl butyral - Saflex UV-40 (Monsanto Chemical Company, Springfield, Massachusetts). Saflex UV-40 is a sheet resin employed in laminating architectural safety glass. The ultraviolet screening agent serves to protect the colors of rugs, fabrics, paintings, etc., behind shopfront windows. It is designed for and restricted to use as a glass laminating material. The other two films - Tedlar UT (0.001 inch) and Llumar (0.005 inch) - cost \$0.046 and \$0.22 per square foot, respectively, or 20 and 95 percent of the 1985 materials cost allocation for the encapsulation task. The Llumar film can obviously not be used; and the Tedlar is still expensive at one-fifth of the total allocation.

Experiments were conducted to determine the feasibility of preparing low-cost, UV-absorbant coatings. Solution acrylic coatings were chosen as the vehicle (Acryloid series; Rohm & Haas Company) due to their low cost, transparency, and inherently excellent weathering characteristics. Three UV absorbers chosen from the benzophenone and benzotriazole classes of UV stabilizers (Table 1) were blended into each of the formulations shown in

Table 3 at two concentrations. Films were subsequently cast and dried to a thickness of 0.001 inch. The 2 and 5 phr concentrations were chosen based on Springborn Laboratories experience; the 5 and 10 phr levels used for Permasorb MA were based on recommendations by National Starch.

Transmittance measurements show these films to be approximately 80 percent transmissive in the visible regions, and from zero to 11 percent transmissive in the ultraviolet range. Four formulations had no transmittance at all in the UV region, and these ranged from $0.0092 to $0.0122 per square foot per mil. This corresponds to approximately 20 percent of the cost of Tedlar or 5 percent of the materials cost allocation. Increase in additive level of the UV stabilizer does not always result in a significant decrease in UV transmission. This may occur because the UV transmission is already low, even at the lower additive concentration. Extensive effort is required to optimize the UV additive system with regard to type and concentration of UV stabilizer(s) and presence of synergists. Optimum systems will also vary with the polymer vehicle.

The efficacy of these coatings in protecting an underlying pottant is not know at this time, but experiments are in progress to generate comparative data on the degree of protection offered by these coatings versus Tedlar and internal compounding of UV stabilizers.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 1

UV Stabilizers

Trade Name	Chemical Name	Function	Manufacturer	Price ($/Lb)
• Benzophenones -				
Uvinul 400	2,4-dihydroxy benzophenone	UV absorber	GAF	6.70
Uvinul D-49	2,2'-dihydroxy-4,4'-dimethoxy benzophenone	UV absorber	GAF	12.40
Cyasorb UV-531	2-hydroxy-4-n-octoxy-benzophenone	UV absorber	American Cyanamid	4.80
Permasorb-MA	2-hydroxy-4-(2-hydroxy-3-methacrylyloxy)-propoxy-benzophenone	UV absorber	National Starch	10.20
• Benzotriazoles -				
Tinuvin 327	2-(3',5'-di-t-butyl-2'-hydroxy phenyl)-5-chlorobenzotriazole	UV absorber	Ciba Geigy	9.75
Tinuvin P	2-(2'-hydroxy-5'-methyl phenyl) benzotriazole	UV absorber	Ciba Geigy	9.25
• Nickel Complexes -				
AM-105	Nickel bisoctyl phenol sulfide	Excited state quencher	Ferro	3.85
Cyasorb UV-1084	[2,2'-thiobis(4-t-octyl phenolato)] n-butyl-amine Nickel II	Excited state quencher	American Cyanamid	5.65
Irgastab 2002	Nickel bis [O-ethyl(3,5-di-t-butyl-4-hydroxy-benzyl)] phosphate	Excited state quencher	Ciba Geigy	8.10
• Acrylonitriles -				
UV Absorber 340	N-(β-cyano-β-carbo-methoxy vinyl)-2-methyindoline	UV absorber	Mobay	10.99

...Continued

TABLE 1 - (Continued - 2)

Trade Name	Chemical Name	Function	Manufacturer	Price ($/Lb)
Acrylonitriles (Continued) -				
Uvinul N-35	Ethyl-2-cyano-3,3-diphenyl acrylate	UV absorber	GAF	8.10
Uvinul N-539	2-ethyl hexyl-2-cyano-3,3-diphenyl acrylate	UV absorber	GAF	6.40
• Benzylidene Malonates -				
Cyasorb UV-1988	(p-methoxybenzylidene) malonic acid, dimethyl ester	UV absorber	American Cyanamid	12.60
Cyasorb UV-3100	(p-methoxybenzylidene) malonic acid, diethyl ester	UV absorber	American Cyanamid	7.60
• Benzoate Esters -				
AM-340	2,4-di-t-butylphenyl-3,5-di-t-butyl-4-hydroxybenzoate	Radical deactivator	Ferro	4.75
Inhibitor RMB	Resorcinol monobenzoate	UV absorber	Eastman	3.47
• Salicylates -				
Inhibitor OPS	p-octylphenyl salicylate	UV absorber	Eastman	Discontinued
Salol	Phenyl salicylate	UV absorber	Dow	2.15
t-Butyl Salol	4-t-butyl phenyl salicylate	UV absorber	Dow	3.60
• Amine -				
Tinuvin 770	Hindered amine	Radical deactivator	Ciba Geigy	13.20

TABLE 2

Antioxidants

Trade Name	Chemical Name	Functions	Manufacturer	Price ($/Lb)
• Alkylated Mono-Phenols				
Ionol	2,6-di-t-butyl-4-methyl phenol	Free-radical scavenger	Shell	1.06
Irganox 1076	Octadecyl 3-(3',5'-di-t-butyl-4'-hydroxyphenyl) propionate	Free-radical scavenger	Ciba-Geigy	3.60
Irganox 1093	O,O-di-n-octadecyl-3,5,-di-t-butyl-4-hydroxybenzyl phosphonate	Free-radical scavenger	Ciba-Geigy	6.70
• Alkylated Bis-Phenols				
Cyanox 2246	2,2'-methylene bis-(4-methyl-6-t-butylphenol)	Free-radical scavenger	American Cyanamid	1.81
Santonox R	4,4'-thiobis-(6-t-butyl metacresol)	Free-radical scavenger; peroxide decomposer	Monsanto	3.40
Irganox 565	2,4-bis(n-octylthio)-6-(4-hydroxy-3,5-di-t-butyl anilino)-1,3,5-triazine	Free-radical scavenger; peroxide decomposer	Ciba-Geigy	(a)
Santowhite	4,4'-butylidene bis(6-t-butyl-m-cresol)	Free-radical scavenger	Monsanto	2.27
• Alkylated Poly-Phenols				
Good-rite 3125	3,5-di-t-butyl-4-hydroxycinnamic acid triester with 1,3,5-tris(2-hydroxyethyl) triazine-2,4,6-trione	Free-radical scavenger	Goodrich	5.00
Irganox 1010	Tetrakis [methylene 3-(3',5'-di-t-butyl-4'-hydroxyphenyl) propionate] methane	Free-radical scavenger	Ciba-Geigy	5.40
Antioxidant 330	1,3,5-trimethyl-2,4,6-tris (3,5-di-t-butyl-4-hydroxy benzyl) benzene	Free-radical scavenger	Ethyl	5.30

(a) Development product

...Continued

TABLE 2 (Continued - 2)

Trade Name	Chemical Name	Functions	Manufacturer	Price ($/Lb)
• Alkylated Poly-Phenols (Continued)				
Topanol CA	3:1 condensate of 3-methyl-6-t-butylphenol with crotonaldelhyde	Free-radical scavenger	ICI	3.89
CAO-30	1,1'-thio bis(2-naphthol)	Free-radical scavenger	Ashland	3.00
• Thiodipropionates				
Cyanox LTDP	Dilaurylthiodipropionate	Peroxide decomposer	American Cyanamid	1.31
Cyanox STDP	Distearylthiodipropionate	Peroxide decomposer	American Cyanamid	1.33
Cyanox 711	Ditridecylthiodipropionate	Peroxide decomposer	American Cyanamid	0.96
• Organic Phosphites				
Polygard	Tri(mixed mono- and dinonyl)	Peroxide decomposer and metal deactivator	Uniroyal	0.62
Wytox 438	Polymeric phosphite	Same	Stepan	0.66
Weston 618	Di(stearyl) pentaerythrityl diphosphite	Same	Borg-Warner	2.45
• Amines				
Agerite White	Sym. dibetanaphthyl-p-phenylenediamine	Free-radical scavenger; copper inhibitor	Vanderbilt	2.59
JZF	N,N'-diphenyl-p-phenylene diamine	Same	Uniroyal	2.07
• Miscellaneous Metal Deactivators				
CHEL 180	Proprietary	Metal deactivator	Ciba-Geigy	6.75
Mark 1475	Proprietary triazole	Same	Argus	11.70
• Dithiocarbamate				
Ethyl Zimate	Zinc diethyldithiocarbamate	Peroxide decomposer	Vanderbilt	1.06

TABLE 3

ORIGINAL PAGE IS OF POOR QUALITY

Ultraviolet-Absorbing Coatings

(Based on Rohm & Haas Acrylics)

Formula A-6693-	Acryloid Number (a)	Absorber (b)	Level (phr) (c)	Optical Transmission (d)		Cost (e)	
				UV 290-350 nm	Visible 350-800 nm	$/lb (Dry)	$/ft²/mil
1	B-44	Uvinul 400	2	6	81.7	1.248	0.0076
2	B-44	Uvinul 400	5	2	79.4	1.415	0.0086
3	B-44	Tinuvin-P	2	3	79.9	1.299	0.0079
4	B-44	Tinuvin-P	5	0	71.7	1.542	0.0094
5	B-72	Uvinul 400	2	11	83.7	1.368	0.0083
6	B-72	Uvinul 400	5	3	83.1	1.532	0.0093
7	B-72	Tinuvin-P	2	5	82.7	1.419	0.0086
8	B-72	Tinuvin-P	5	0	81.6	1.659	0.0102
9	B-82	Uvinul 400	2	9	83.5	1.200	0.0073
10	B-82	Uvinul 400	5	1	82.6	1.368	0.0083
11	B-82	Tinuvin-P	2	1	82.8	1.251	0.0076
12	B-82	Tinuvin-P	5	0	82.1	1.495	0.0092
13	B-44	Permasorb-MA	5	5	83.0	1.590	0.0097
14	B-44	Permasorb-MA	10	1	80.8	2.043	0.0125
15	B-72	Permasorb-MA	5	9	80.0	1.707	0.0104
16	B-72	Permasorb-MA	10	2	82.0	2.154	0.0132
17	B-82	Permasorb-MA	5	2	81.8	1.543	0.0094
18	B-82	Permasorb-MA	10	0	80.8	1.999	0.0122

(a) Solution acrylic coatings

(b) Absorber dissolves in acrylic solution by stirring at 60°C for 20 minutes. Formulations also contain 1% Cyasorb UV-1084 quencher for additional stability.

...Continued

TABLE 3 (Continued - 2)

Formula A-6693-	(a) Acryloid Number	(b) Absorber	(c) Level (phr)	(d) Optical Transmission		(e) Cost	
				UV 290-350 nm	Visible 350-800 nm	\$/lb (Dry)	\$/ft²/mil
Comparative Materials:							
UV-40	Saflex	Proprietary	?	0	75.2	-	-
BG30-UT	Tedlar	Proprietary	?	0	90 [f]	6.75	0.0482

(c) phr = Parts per hundred parts resin, based on solids content.

(d) Integrated transmissions on 1-mil films.

(e) Based on assumed average density of 1.18, or 0.0426 lb/in.^{3}.

(f) Based on manufacturer's data for this film.

5. ENCAPSULATION DESIGNS AND MATERIALS

INITIALLY SELECTED MATERIALS

Twenty-four materials were originally selected for study in this program, on the basis of transparency and weatherability. Most of the originally investigated polymers proved to be cost-ineffective and/or not amenable to any processing method that could be used to encapsulate solar cells. The selection of materials was directed solely at transparent pottants and did not include other possible construction elements such as substrate materials; protective coatings were briefly investigated. Useful information has been obtained, however, that provides a good base of experience and accumulated data that is applicable to further material studies.

In a continuation of this original program, data are being obtained from outdoor exposures as well as from the original accelerated aging exposures so that correlations between natural and artificial accelerated environments may be made. No final conclusion can be drawn at this time, as the polymers under investigation have not finished their exposure terms under natural conditions. Tensile bar samples were put outdoors in Florida and Arizona at 45^{o} angle exposure, and in Arizona in the EMMAQUA (a device combining natural sunlight with artificial acceleration by means of mirror concentrators plus a water spray). Encapsulated cells are under exposure in Arizona in the EMMAQUA.

The first set of data from an outdoor EMMAQUA accelerated aging condition has been obtained. Table 4 shows the change in properties of ten polymers after four months of exposure to EMMAQUA. The materials were chosen for this outdoor accelerated exposure on the basis of elongation results following accelerated indoor aging. We purposely chose polymers ranging from excellent to poor to examine the correlation between RS-4, Weather-Ometer, and oven aging with outdoor normal and EMMAQUA accelerated exposure.

All polymers except polyvinyl butyral (PVB) were exposed as tensile bars fastened to a stainless steel mesh backing. PVB is being exposed in the form of tensile bars sandwiched between glass and FEP, with glass on the exposed side. This is not a laminate.

Table 5 compares the results of loss of visible optical transmission and elongation at break after four months outdoors under EMMAQUA with 240 days under the RS-4 Sunlamp and the Weather-Ometer. In general, correlation is good. It is obvious that those sample materials that are excellent outdoors are also stable under accelerated indoor aging - e.g., Halar 500 and FEP 100. Similarly, Tenite 479 and Lexan 123 are poor in both the accelerated indoor weathering and the EMMAQUA outdoor weathering. There is an approximately similar transmission loss for Tedlar 20 both indoors and outdoors. Sylgard 184 evidences a loss of over half of its transmission in both the wet EMMAQUA and the wet Weather-Ometer, but not in the dry RS-4 Sunlamp. This reconfirms previous conclusions that silicones are moisture-sensitive in the presence of UV light.

It is too soon to draw any definite conclusions, but it is hoped that the EMMAQUA experiments and information resulting from the other accelerated test methods can eventually be assembled into a coherent presentation from which positive correlations may be drawn. Conclusions resulting from this study will be invaluable for the rapid selection and evaluation of future materials.

Variations in mechanical properties versus temperature were also part of the original endeavor to characterize material performance. Tables 6 through 9 present the measurements of tensile strength, elongation at break, tensile modulus, and yield strength for twelve polymers at six temperatures between -20°C and +80°C. Generally, tensile strength and yield strength can be seen to decrease with increasing temperature, while modulus and ultimate elongation show considerable variation.

Another basic material property, coefficient of thermal expansion, appears in Table 10. Linear thermal expansion was determined on nine materials from the original program using test method ASTM D-696. Manufacturers and literature supplied values for an additional six materials. It can be readily observed that the polymers investigated have coefficient of expansions of approximately eight to sixty times that of silicon. This indicates that stresses will appear on solar cell wafers encapsulated in any one of these materials upon thermal cycling. However, materials of low modulus should be capable of absorbing the stress without damage to the cell, as, for example, silicone resin.

DESIGNS AND CONSTRUCTION ELEMENTS

An improved approach of broader scope for the successful selection of potentially useful materials was derived from the specification of design elements. On the assumption that the flat-plate collector is the most efficient construction, nine different design options can be considered and are presented in Figure 2. The designs are useful to determine the number of glue lines, fabrication processes, material cost estimates, etc. Using the flat-plate model, six construction elements may be discovered:

1. Outer covers (e.g., conformal, UV screen, protective)
2. Substrates (structural, load-bearing)
3. Pottants
4. Superstrates (structural, load-bearing)
5. Back covers
6. Adhesives

Materials may now be identified in terms of their function(s), or functions can be described and specific materials recommended to suit the use.

The substrate/superstrate materials are briefly summarized in Table 11. This listing of potentially useful structural materials is just a first cut; other materials will be added on further investigation - e.g., other fiberglass filled compounds, etc. Costs are normalized to 0.1 inch thickness for the purpose of comparison. The least expensive substrate material found is chip board at $0.042 per square foot. However, it is cost per unit of rigidity that is most important and not merely cost per pound. The rigidity is needed in the substrate to withstand wind loading.

The transparent polymer which will be used to encapsulate the solar cell is perhaps the most critical construction element. This encapsulant must withstand long years - up to 20 or more for the long-range goal - of weathering under a wide variety of conditions. It must do so with minimum loss of transparency and without excessive loss of physical properties.

The polymers that are most weather resistant are also the most costly - i.e., the fluorocarbons. Acrylics are also highly weatherable and very much more reasonable in price, but those investigated in the original program were not fabricable due to high melting point and excessive rigidity.

We will now explore two routes to a cost-effective encapsulant:

1. Investigate the Availability of Fabricable Acrylics

A broad ranging survey is being conducted with all acrylic manufacturers to find an acrylic - probably a copolymer - that will be fabricable at reasonable temperatures (below 250-300°F) and still be weather resistant. This data will be made available in the next quarterly report.

2. Use of a Fabricable and Less Expensive Polymer That Is Not UV Stable

Many polymers are available at under $1.00 per pound. Unfortunately, with the exception of acrylic, they are all unstable to weathering - i.e., UV-catalyzed oxidation.

It will be necessary not only to stabilize the selected polymer with internally compounded additives but also to protect it externally with a coating or film containing high concentrations of UV stabilizers.

Table 12 - parts A through D - contains a listing of all (hopefully) U. S. manufactured transparent commercial polymers. The table is set up to include in the first section a description of the polymer - i.e., its generic chemical type, at least one of its trade names, and the manufacturer. A given polymer is often available through other producers, but for the sake of convenience only one has been listed.

The next section of the table describes processability as being either in liquid or solid form. Liquid signifies a casting process. Under solid the fabrication temperature is shown as either less than ($<$) or greater than ($>$) 250°F (a few are at 250°F). It is essential that the fabrication (extrusion, compression molding, injection molding, thermoforming) temperature be below 350°F to avoid melting the solder and to avoid the need for high forming pressures that would crack the brittle silicon cell. The $250^{\circ}F$ temperature is an approximation and should allow a sufficient safety factor.

In the central portion of the table is a column showing the survival prognosis; this involves the survival span in years of unprotected materials. In the next column is shown an upgrading potential in years of completely protected polymers. By complete protection we imply a high level of an internal UV additive synergistic system and a film or coating containing a high level of UV absorber to screen out the impinging UV light. All of these figures are educated opinions, since this type of information is rarely available. The years predicted for the virgin polymer are given in ranges and those for the protected polymer as Fair (F) or Good (G) at 10 and 20 years of lifetime.

The following portion of the table contains literature information on properties - hydrolysis resistance (educated opinion), tensile modulus, refractive index, density, and coefficient of thermal expansion. We chose what we considered to be the most important properties. Stiffness (modulus) is critical to fabrication; if there is too much stiffness, the polymer would require such a high pressure to be fabricated that it would crack the cell. In addition, a soft plastic may be necessary to absorb stress generated by the difference in coefficient of thermal expansion between inorganic silicon and an organic polymer.

The final (extreme right) portion of the table covers costing in terms of cost per pound, cost per volume as $/cubic inch, fill (space between cells) cost as $/square foot, and the cost for an additional 5-mil (0.0005 inch) protective covering for the cell. The total encapsulant cost is the sum of the fill and the cover cost.

We have condensed the list of transparent polymers into a small group of materials in Table 13 which are, or at least have the potential of being, easily processable. This table is divided into two groups: those polymers that can be cast and those that are fabricable below approximately $250^{\circ}F$. Only those polymers are included in this table whose all-around properties offer chance of success. By this we mean:

a. The price must be reasonable.

b. Stiffness modulus must be relatively low.

c. The polymer must be processable.

d. There must be a reasonable possibility that the polymer can be upgraded to last 10 years and hopefully 20 years through internal and external protection.

e. The polymer must have reasonable physical properties. This rules out, for example, the cheap but brittle hydrocarbons from Neville Chemical.

f. The polymer sheet must be transparent.

The principal example of a casting resin is the presently used silicone. The silicones have the obvious disadvantage of price. Cast acrylics are much lower in cost. However, we must be careful that we use a casting resin that is flexible - i.e., one having a relatively low modulus - to provide stress relief because of the difference in coefficient of thermal expansion between silicon and polymer. There are two types of hot melts being considered: ethylene/vinyl acetate copolymer, and acrylics. A thermoset polyester is included. Polyvinyl chloride copolymer is included in the top group as a plastisol and in the bottom group as a plasticized resin. One aliphatic urethane has been found so far.

The solid polymer/low temperature fabricable group is headed by polyvinyl butyral (PVB). This material is sold in plasticized form; and one grade, of course, is the familiar safety glass interlayer in automobiles. Both our recent work and considerable prior study at Monsanto (the manufacturer) indicate that unprotected PVB, as expected, is a UV- and thermally unstable polymer. By "as expected" we mean that there is no theoretical or practical reason why PVB should be UV/oxidation stable. When PVB is laminated between glass, both oxygen and moisture are excluded. THIS IS THE PRIMARY REASON WHY PVB IS STABLE AS A SAFETY GLASS INTERLAYER - AND MONSANTO AGREES.

We will conduct UV exposure experiments in the presence and absence of air and moisture to reprove this point. Monsanto will also provide us with special grade of PVB stabilized with internally compounded UV additives. They claim that this material will last at least 10 years, and perhaps longer, without further protection. Monsanto people also state that the hydrolytic sensitivity of PVB is not inherent in the polymer but is caused by impurities.

The solid, low-melting ethylene copolymers shown in the table are not stable to UV but with both internal protection and external screening offer the possibility as a long-term encapsulant.

Finally, again we have the potential of a low-melt[illegible] rylic co-polymer.

All of the candidates in this final table (Table 13) will be investigated as encapsulation candidates.

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4

EMMAQUA Exposure
Desert Sunshine Exposure Tests, Inc.

Langleys: 503,340   Time: 4 Months   Dates: 5/15/77-9/15/77

Resin	Optical Transmission (%)				Mechanical Properties								Remarks
	UV		Visible		Yield Str. (psi)		Modulus (psi x 10^5)		Elongation (%)		Tensile Str. (psi)		
	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	
Halar 500	36	29	81	62	5030	4483	2.23	2.1	175	182	6090	5285	(a)
Tedlar 20	13	4	76	19	5820 (b)	5754	3.60	2.29	120	145	12,100	10,446	(a)
Plexi DR-61K	0	1	90	75	5630	6120	2.20	2.38	17	13	5380	5763	(a)
FEP-100	34	35	84	65	2130 (b)	1913	0.704	0.71	220	263	2800	3269	(a)
Tenite 479	44	(c)	92	44	3470	NY	1.54	1.77	81	< 1	4400	812	Embrittled
Sylgard 184	32	7	76	30	NY	NY	586 (e)	0.0038 (f)	106	80	930	532	Dirt accumulation
Kel-F 6060	24	18	82	57	5690	4447	1.72	1.64	130	70	5680	3861	(a)
Lexan 123	0	0	88	64	8500	8322	3.14	3.32	104	14	8160	6674	Yellow, hazy
Plexi V-811	75	72	92	79	9030	NY	4.18	4.37	5	2	9030	5520	(a)
Saflex PT - PVB	-	(d)	90	(d)	830	(d)	0.051	(d)	180	(d)	4010	(d)	Yellow, flowed

Code: Cont. = Control
Exp. = Exposed
Str. = Strength
NY = No Yield

(a) No apparent visual change
(b) Pseudo yield point
(c) Broken
(d) Material flowed
(e) Modulus at 100 percent
(f) Modulus at 50 percent

TABLE 5

Comparison of Outdoor EMMAQUA Aging with Accelerated Aging Under the RS-4 Sunlamp and Weather-Ometer

Polymer	Visible Transmission (%)[a]				Tensile Elongation (%)			
	Unaged Control	4 Months in the EMMAQUA	240 Days (b) RS-4	240 Days (c) W-O	4 Months in the EMMAQUA	Unaged Control	240 Days RS-4	240 Days W-O
Halar 500	81	62	70	71	175	182	234	255
Tedlar 20	76	19	34	30	120	145	89	172
FEP 100	84	65	68	78	220	263	265	312
Kel-F 6060	82	57	68	68	130	70	150	165
Sylgard 184	76	30	64	26	106	80	87	88
Plexiglas V 811	92	79	76	81	5	2	1.5	2
Plexiglas DR 61K	90	75	80	78	17	13	1	4
Tenite 479	92	44	(d)	(d)	81	80	(d)	(d)
Lexan 123	88	64	(d)	(d)	104	14	(d)	(d)

(a) 350-800 nm

(b) RS-4 Sunlamp, 55°C

(c) Weather-Ometer, 55°C

(d) Degraded

TABLE 6

Mechanical Property/Temperature Variation

Property: Ultimate Tensile Strength (psi)

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	8180	8470	8405	6015	5900	4950
Tedlar 20	DuPont	15,145	13,705	12,510	8060	7890	7785
Plexi DR-61K	Rohm & Haas	-	7705	5525	4355	2985	2300
FEP-100	DuPont	5275	4950	3860	3295	2070	1725
Tenite 479	Eastman	-	5070	4695	3555	3230	2165
Sylgard 184	Dow Corning	505	520	450	380	340	315
RTV 615	G.E.	775	510	460	570	405	730
Kel-F 6060	3M	8825	7330	5655	4150	3200	3025
PFA 9705	DuPont	4600	4615	4030	3010	3430	2680
Plexi V-811	Rohm & Haas	-	5925	9135	8240	5745	4225
Viton A-HV	DuPont	3060	NB[a]	NB[a]	NB[a]	115	90
C-4 Polycarbonate	Union Carbide	-	6675	5365	4455	3800	3035

(a) No break; elongation exceeds machine capacity.

TABLE 7

Mechanical Property/Temperature Variation

Property: Elongation at Break (%)

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	285	290	275	265	365	445
Tedlar 20	DuPont	200	220	155	140	135	160
Plexi DR-61K	Rohm & Haas	-	20	25	45	90	150
FEP-100	DuPont	640	690	330	310	295	225
Tenite 479	Eastman	-	60	80	75	100	95
Sylgard 184	Dow Corning	230	210	110	70	85	65
RTV 615	G.E.	430	420	120	110	100	110
Kel-F 6060	3M	50	80	175	180	280	310
PFA 9705	DuPont	520	540	280	255	325	365
Plexi V-811	Rohm & Haas	-	20	5	5	10	15
Viton A-HV	DuPont	200	>700[(a)]	>1000[(a)]	>500[(a)]	185	70
C-4 Polycarbonate	Union Carbide	-	30	50	45	60	75

(a) Elongation exceeds machine capacity

TABLE 8

Mechanical Property/Temperature Variation

Property: Modulus x 10^5 psi

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	1.64	2.50	1.50	1.30	0.91	0.24
Tedlar 20	DuPont	0.94	0.80	3.21	1.50	0.68	0.38
Plexi DR-61K	Rohm & Haas	-	1.28	2.90	2.35	1.35	1.10
FEP-100	DuPont	0.17	0.20	0.62	0.49	0.38	0.18
Tenite 479	Eastman	-	3.76	1.73	1.38	1.06	0.19
Sylgard 184 (a)	Dow Corning	100	120	230	330	270	335
RTV 615 (a)	G.E.	105	60	160	210	275	310
Kel-F 6060	3M	0.22	0.24	1.13	1.05	0.32	0.20
PFA 9705	DuPont	0.19	0.19	0.49	0.44	0.39	0.19
Plexi V-811	Rohm & Haas	-	1.20	4.98	4.60	3.49	2.36
Viton A-HV (a)	DuPont	7680	375	260	230	175	160
C-4 Polycarbonate	Union Carbide	-	6.22	2.25	2.65	2.25	2.16

(a) Figures shown indicate psi x 1.0 at 50 percent elongation

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 9

Mechanical Property/Temperature Variation

Property: Yield Strength (psi)

Resin	Manufacturer	Temperature					
		-20°C	0°C	23°C	40°C	60°C	80°C
Halar 500	Allied	7835	8145	5355	3780	2550	1495
Tedlar 20	DuPont	9790	9460	6140	3835	2875	2200
Plexi DR-61K	Rohm & Haas	-	8200 (a)	6100	4865	2805	2390
FEP-100	DuPont	2935	2590	2145	1665	1305 (b)	970 (b)
Tenite 479	Eastman	-	5270	4320	3090	2305	1650
Sylgard 184	Dow Corning	NY	NY	NY	NY	NY	NY
RTV 615	G.E.	NY	NY	NY	NY	NY	NY
Kel-F 6060	3M	NY	8675	5570	3990	2615	1770
PFA 9705	DuPont	2685	2530	1860	1730	1325 (b)	1055 (b)
Plexi V-811	Rohm & Haas	-	NY	NY	NY	6525	5250 (c)
Viton A-HV	DuPont	NY	NY	330	185	NY	NY
C-4 Polycarbonate	Union Carbide	-	NY	5480	4740	3915	3285

(a) Two samples yielded; one sample had no yield. NY = No Yield

(b) Pseudo yield point

(c) Two samples had no yield; one sample yielded.

TABLE 10

Linear Thermal Expansion
ASTM D696

Resin	(In./in./C°) X 10^{-5}
Coatings/Encapsulants	
Halar 500	8.6
Plexiglas DR-61	9.3
FEP 100	11.7
Tenite 479 CAB	14.5
Kel-F 6060	7.0
PFA 9705	15.7
Plexiglas V811	6.3
C-4 Polycarbonate	9.7
Lexan 111-123	3.7
Tedlar	2.8 [a]
Sylgard 184	30.0 [a]
RTV 615	27.5 [a]
Q3-6527 Gel	1.45×10^{-3} [b]
Solar Cells	
Silicon	0.3-0.7 [c]
Solder	2.5 [c]

(a) Value submitted by manufacturer.

(b) Cubical expansion: $cm^3/cm^3/^oC$.

(c) Handbook of Chemistry and Physics; Chemical Rubber Publication Company, 30th Edition (1948).

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 11

Sub/Super-Strate Materials

Material	Manufacturer	Cost ($/lb)	Density (lb/cu in.)	Cost/Vol. ($/in.^{3})	Coefficient of Thermal Expansion (10^{-5} in./in./°C)	Flexural Modulus (10^5 psi)	Cost/Thickness ($/ft^2/0.1")	Remarks
Wood - 1/2" Int. plywood	Numerous	*0.14	0.020	0.00288	Varies: ≈1.0	Low	0.0445	*Typical oven-dry wood; varies considerably.
Aluminum, T6 0.05" sheet	ALCOA; Reynolds	0.856	0.096	0.082	2.4	-	1.18	-
TUFFAK, polycarbonate, double-wall construction; 0.220".	Rohm & Haas	4.40	0.008 (1)	0.0352	6.6	3.2	0.51	Probably not available in this gauge.
Acrylic sheet, 0.125"	Rohm & Haas	1.42	0.0433	0.061	7.0	3.0 (2)	*1.04	*Market
Polycarbonate; 0.060"	G.E.; Rohm & Haas	1.84	0.0433	0.077	6.6	3.2	*1.16	*Market
Polypropylene, black, filled (30%)	Numerous	0.30 (3)	0.040	0.012	2.9	4.0	0.173	Mostly captive sheet production.
Polypropylene, black, glass-coupled (30%)	Numerous	0.57 (3)	0.0417	0.0237	4.0	8.5	0.341	Mostly captive sheet production.
ABS sheet, 0.120"	Numerous	0.70 (3)	0.038	0.0266	6.0-8.0	3.0-3.5	0.383	Mostly captive sheet production.
Styrene sheet	Numerous	0.38 (3)	0.0375	0.01425	6.0-8.0	1.5-2.8	0.205	Mostly captive sheet production.
Window glass; 80- to 100-mil	PPG	0.97	0.089	0.086	0.85	(4)	1.22	-

(1) Calculated, based on cellular construction.

(2) Deteriorates over a period of time.

(3) Computed, based on known conversion costs.

(4) Extremely high.

...Continued

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 11 (Continued - 2)

Material	Manufacturer	Cost ($/lb)	Density (lb/cu in.)	Cost/Vol. ($/in.^{3})	Coefficient of Thermal Expansion (10^{-5} in./in./°C)	Flexural Modulus (10^5 psi)	Cost Thickness ($/ft^2/0.1")	Remarks
Stainless steel sheet	Numerous	1.13	0.286	0.323	0.36-0.50	..	4.59	-
Sheet steel, hot-rolled	Numerous	0.154	0.283	0.043	0.36-0.50	-	0.61	-
Polypropylene structural foam	Hercules	0.801[3]	0.020	0.016	2.3	≈ 10	0.23	Few custom producers; must be molded.
ABS structural foam	Borg-Warner	1.00[3]	0.024	0.024	2.9	≈8-10	0.346	Ditto
Phenolic/glass, structural	Resin: Hooker; G.E.	0.55[3]	0.0636	0.035	1.5-2.0	25.0	0.504	Would require tooling.
Polyurethane, rigid, foamed	Resin: Upjohn	0.77[3]	0.0116	0.0089	15	0.4-0.6	0.129	20 lb/ft^3
SMC molded (polyester) sheet	Several: e.g. Budd	0.922	0.0722	0.0666	2.0	16	0.96	Assumes major SMC facility.
NEMA G-10 epoxy/glass	Poly-Ply	-	-	-	-	-	2.94	-
Chip board (particle board)	Georgia-Pacific	0.0948	0.0310	0.00294			0.0423	

TABLE 12-A

Transparent Plastics Survey

Materials Under 50 Cents/Pound

Generic Type	Trade Name	Manufacturer	Processability		(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years		(a) Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm^3)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	Cost/Vol. ($/in^3)	Fill Cost ($/ft^2)	Cover Cost 0.0005 in. ($/ft^2)
			Liquid	Solid (°F)		10	20									
Hydrocarbon polymers	Polyvol G100	Velsicol		< 250	<1	P	P	G		~1.50	1.0		0.30	.0196	.0131	.0141
Hydrocarbon polymers	X 125, 685	Neville	Yes		<1	P	P	G			1.0		0.23	.0150	.0100	.0108
Polyvinyl chloride (PVC)	Geon 103	Goodrich		> 250	1-5	G	P	G	2-4	1.52-1.55	1.32-1.40	5-10	0.26	.0106	.0071	.0076
Polystyrene	Cosden 500	Cosden Oil		> 250	1-5	F-G	P-F	G	4-5	1.59	1.04-1.09	6-8	0.27	.0103	.0069	.0074
Polypropylene	Profax 6523	Hercules		> 250	< 1	F-G	P-F	G	1.5-2.5	1.49	0.90-0.93	2-20	0.30	.0099	.0066	.0071
Poly-α-methyl styrene	Resin 18	AMOCO		> 250	1-5	F	P	G	4-5	~1.60	1.08		0.28	.0109	.0073	.0078
High-density polyethylene	Dow 75731	Dow		> 250	1-5	G	P	G	0.75-1.60	1.26*	0.92-0.96	10-20	0.29	.0105	.0070	.0076
Low-density polyethylene	DYNH	UCC		250	1-5	G	F	G	0.14-0.38	1.159**	0.90-0.98	10-20	0.31	.0105	.0070	.0076
Ethylene/vinyl acetate	EVA 3185	Du Pont		< 250	1-5	G	P	P-G	0.002-0.04	1.51-1.54	0.92-1.10	10-20	0.50	.0127	.0085	.0091
Plasticized PVC Copolymer	Numerous			> 250	1-5	G	P	P-G	0.01-0.20		1.2		0.30-0.40	.0152	.0101	.0109
Ethylene/ethyl acrylate	DPD 6169	UCC		< 250	1-5	G	F	P-G	0.02-0.4	~1.51	0.90-0.93	16-25	0.48	.0135	.0090	.0097
Isophthalic polyester	Aropol	Ashland	Yes		1-5	G	F	P-F	4-6(d)		1.2		0.37	.0160	.0107	.0115
Styrene/acrylonitrile	Lustran	Monsanto		> 250	1-5	F	P	G	5.0	1.57	1.06	7	0.40	.0153	.0102	.0110

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; F = Fair; P = Poor

* Marlex 50 at 130°C

** Alathon 10 at 90°C

(d) A flexible polyester is available

...Continued

TABLE 12-A

Materials Under 50 Cents/Pound (Continued -2)

Generic Type	Trade Name	Manufacturer	Processability		Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years		Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm^3)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	Cost/Vol. ($/in^3)	Fill Cost ($/ft^2)	Cover Cost 0.0005 in. ($/ft^2)
			Liquid	Solid (°F)		10	20									
Styrene/butadiene	Kraton	Shell		> 250	< 1	P	P	G	0.3-0.5	1.52-1.55	1.04-1.06	3-10	0.35-0.43	.0142	.0095	.0102
Propylene/ethylene	Polyallomer 5021E	Eastman		> 250	< 1	P	P	G		1.49	0.90	8-10	0.395(e)	.0133	.0089	.0096
Neopentyl glycol polyest.	Cargill 5446	Cargill	Yes		1-5	G	P	P	4-7(f)		1.2		0.38	.0165	.0110	.0118
Ethylene propylene rubber	Nordel	DuPont		250	1-5	G	P	G	0.01-0.50	1.52-1.55	0.7-1.20		0.49	.0185	.0124	.0133
Chlorinated polyethylene	CPE	Dow		250	1-5	P-G	P-P	G	~0.02	1.52	1.16-1.25		0.44	.0190	.0127	.0137
Polybutylene	Witron	WITCO		> 250	< 1	P	P	G	0.26-0.50	1.50	0.91-0.92	15	0.48	.0158	.0106	.0114
PVC Plastisol Copolym.	Numerous		Yes		1-5	G	P	G	0.02-0.20		1.2		0.50-0.60	.0238	.0159	.0171

(e) Cost, with UV absorber, 0.465 $/lb

(f) A flexible polyester is available

TABLE 12-B

Transparent Plastics Survey

Materials Costing 50 Cents to $1.00/Pound

Generic Type	Trade Name	Manufacturer	Processability: Liquid	Processability: Solid (°F)	(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years: 10	(a,c) Upgrading Potential in Years: 20	(a) Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm^3)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	Cost/Vol. ($/in^3)	Fill Cost ($/ft^2)	Cover Cost 0.0005 in. ($/ft^2)
Unfilled cast phenolic	Gen-El	G.E.	Yes		< 1	P	P	G	4.0-7.0	1.5-1.7	1.24-1.30	6.8	0.50-0.60	.0252	.0169	.0181
Modified polyethylene terephthalate	Kodar PETG	Eastman		> 250	1-5	G	F	F-G	2.9		1.27		0.55	.0252	.0169	.0181
Clear acrylonitrile/butadiene/styrene (AMBS)	Cycolac CIT	Marbon		> 250	1-5	F-G	P-F	G	2.9-3.4	1.54	1.07	9.5	0.48-0.58	.0204	.0137	.0147
Ethylene/acrylic acid	EAA 435	Dow		< 250	1-5	F-G	P-P	G	~0.06	1.48	~0.43		0.50	.0169	.0113	.0122
Acrylic multipolymer	XT 250	Am. Cyanamid		> 250	1-5	F	P	G	3.1-4.3	1.52	1.11	6-9	0.53	.0212	.0142	.0153
Polybutadiene	Poly BD	ARCO	Yes		< 1	P	P	G	.005-.05	~1.50	0.97		0.62	.0216	.0145	.0156
Ionomer	Surlyn 1707	Du Pont		< 250	< 1	F-G	F-P	F	0.2-0.5		0.94-0.96		0.62-0.66	.0218	.0146	.0157
Acrylonitrile/rubber/multi-polymer	Barex	SOHIO		> 250	1-5	F	P	G	4.9	~1.50	1.15		0.65	.0270	.0181	.0194
Melamine formaldehyde *	Cymel	Am. Cyanamid	Yes		5-10	G	F-G	G	11.0	-	~1.50	4.5	0.55-0.60	.0308	.0206	.0222
Polybutadiene telomer		Lithium Corp.	Yes		< 1	P	P	F-G	5.6	1.49	0.97		0.70	.0245	.0164	.0176
Polyvinyl alcohol	Gelvatol	Monsanto		< 250	1-5	F	P	P	2-4	1.45	1.19-1.27	10	0.76	.0337	.0226	.0243
Cellulose propionate	Tenite	Eastman		> 250	1-5	G	F	F	0.1-2.15	1.48	~1.25	11-16	0.85	.0387	.0257	.0276

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; F = Fair; P = Poor

* Not sold unfilled; data are on cellulose-filled product.

...Continued

TABLE 12-B

Materials Costing 50 Cents to $1.00/Pound (Continued - 2)

Generic Type	Trade Name	Manufacturer	Processability		Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years		Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm^3)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	Cost/Vol. ($/in^3$)	Fill Cost ($/ft^2$)	Cover Cost 0.0005 in. ($/ft^2$)
			Liquid	Solid (°F)		10	20									
Cellulose acetate butyrate	Tenite 479	Eastman		> 250	4-5	G	P		2.0- 2.5	1.47	1.15- 1.22	11-17	0.85	.0362	.0242	.0260
Cellulose acetate	Tenite	Eastman		> 250	1-5	G	P		3.0- 6.0	1.48	1.28- 1.32	8-16	0.87	.0408	.0273	.0294
Chlorosulfonated poly- ethylene	Hypalon	DuPont		> 250	1-5	G	P				1.07- 1.27		0.68- 0.78	.0308	.0206	.0222
Thermoplastic polyester	Vitel	Goodyear		> 250	1-5	G	P		NA	~1.50	1.31- 1.40	NA	0.90	.0441	.0295	.0318
Vinyl chloride/vinyl acetate	VYHH	UCC		> 250	1-5	P	P		NA	1.47	~1.50	NA	0.50- 0.60	.0297	.0199	.0214
Linear epoxy	Phenoxy	UCC		> 250	< 1	P-G	P				1.18		0.82- 1.17	.0426	.0286	.0307
. Hot Melts																
Ethylene/vinyl acetate	Bostik 4364	Bostik (USM)	Yes		1-5	G	P-						0.80- 0.90			
Polyamide	Versalon 1112 Milvex 1000	General Mills			< 1	P	P						1.73- 3.05			
Acrylic (solid materials)	329-002 68-42	Daubert Williamson			8-10 8-10	G G	G G						0.56 (d) 3.00			
. Acrylics (e)																
Copolymer	Plexiglas DR100	Rohm & Haas		> 250	5-10	G	G		2-3	1.49	1.15	4-6	0.91	.0377	.0253	.0271
Homopolymer	Plexiglas V811	Rohm & Haas		> 250	16-20	G	G		4.3	1.49	1.19	6-8	0.78	.0391	.0262	.0282
MMA*/styrene (60% MMA) MMA /styrene (85% MMA)	P205 P301	Richardson		> 250 > 250	5-10 8-10	G G	G G		4.6 4.7	1.53 1.56	1.13 1.09	5 4-6	0.46 0.55- 0.60	.0187 .0220	.0125 .0147	.0135 .0158

(d) Sounds low.

(e) There will be a separate, more detailed, list for acrylics at a later date.

*MMA = Methyl methacrylate

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 12-C

Transparent Plastics Survey

Materials Costing $1.00 to $4.00/Pound

Generic Type	Trade Name	Manufacturer	Processability: Liquid	Processability: Solid (°F)	(a,b) Survival Prognosis: Max. Span of Years to Failure	(a,c) Upgrading Potential in Years: 10	(a,c) Upgrading Potential in Years: 20	(a) Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm^3)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	Cost/Vol. ($/in^3)	Fill Cost ($/ft^2)	Cover Cost 0.0005 in. ($/ft^2)
Epoxy urethane	Isochem UE5	Isochem	Yes		< 1	F	P	P-F	0.3-3.5	1.60	1.2-1.3	10-20	1.25	.0563	.0377	.0405
Castable urethane	System 30	Castor	Yes		< 1	F	P	P-F	0.1-3.5	1.55	1.07	1.7-7.4	1.00-1.25	.0436	.0292	.0314
Nylon copolymer	Versalon	General Mills		< 250	< 1	F	P	P-F	1.8-2.9	1.5	1.06-1.08	5.2	1.75	.0675	.0452	.0486
Poly(4-methyl pentene)	TPX RT18	ICI		> 250	< 1	F	P	G	1.6-2.8	1.5	0.83-0.84	2.5	1.75	.0524	.0351	.0377
Polyvinyl butyral	Butvar	Monsanto		> 250	1-5	G	F	F	3	1.48	1.05		1.50	.0568	.0380	.0409
Polycarbonate (stabilized)	Lexan 123-111	G.E.		> 250	10-20	G	G	F	3.1	1.59	1.20	3.7	1.00	.0433	.0290	.0312
Polycarbonate (hydrogenated)	C-4	UCC		> 250	4-5	G	F	F	1.7	1.46	1.2	9.7	2.00-4.00	.0485	.0325	.0349
MMA* casting resin	TS 520	Houghson	Yes		8-10	G	G	G	4.5	1.49	1.18	4-6	1.65	.0703	.0470	.0506
	Tame 500	B.F. Goodrich	Yes		8-10	G	G	G	4.5	1.50	1.19	4-6	1.50	.0644	.0431	.0464
Nylon 6/12	Capron	Allied Chem.		> 250	1-5	F	P	P-F	1.8-2.9	-	1.07	5.2	3.05	.1177	.0789	.0847
Polyaryl sulfone	Udel 1700	UCC		> 250	1-5	F	P	F	3.3	1.63	1.24	3.5	3.00	.0134	.0090	.0096
Polyglycol epoxy	DER 732	Dow	Yes		1-5	F	P	F	1.5-3.0	1.55			.00			
Epoxy casting resin	Eccogel 1265	Emerson & Cummings	Yes		1-5	F	P	F-G	0.3-3.5	1.54	1.20		.50	.1515	.1015	.1091
	Stycast 1264		Yes		1-5	F	P	F-G		1.54	1.10		3.50	.138	.0931	.1000
Polysulfone	Radel P Natural	UCC		> 250	< 1	F	P	F-G	3.1	1.60	1.29	2.8	3.00-5.00	.1861	.1247	.1340
Diethylene glycol diallyl carbonate	CR-39	PPG		250	5	G	F	F	3	1.50	1.3-1.4	4.9	4.00	.1948	.1305	.1402

(a) Springborn Laboratories educated opinion

(b) No UV absorber

(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

Code: G = Good; F = Fair; P = Poor

TABLE 12-D

Transparent Plastics Survey

Materials Costing More Than $4.00/Pound

Generic Type	Trade Name	Manufacturer	Processability: Liquid	Processability: Solid (°F)	Survival Prognosis: Max. Span of Years to Failure	Upgrading Potential in Years: 10	Upgrading Potential in Years: 20	Hydrolysis Resistance	Tensile Modulus (10^5 psi)	Refractive Index	Density (g/cm³)	Thermal Expansion (10^{-5} in/in/°C)	Cost ($/lb)	$/Vol. ($/in³)	Fill Cost ($/ft²)	Cover Cost 0.0005 in. ($/ft²)
Silicone gel	63-6527	Dow	Yes		8-10	G	G	P	(d)	1.44	0.97(d)	(d)	3.75	.1313	.0878	.0945
Cycloaliphatic epoxy	ERL 4221	UCC	Yes		4-5	G	P	P	0.1-1.0		1.18		1.40	.0596	.0399	.0429
Polyvinylidene fluoride	Kynar 460	Pennwalt		> 250	> 20	G	G	G	2.18	1.42	1.76	2.0	5.00	.3496	.2342	.2517
Perfluoroethylene propylene	FEP 100	Du Pont		> 250	> 20	G	G	G	0.70	1.34	2.15	3-4	6.00	.4537	.3040	.3267
Ethylene/chlorotrifluoroethylene	Halar 500	Allied Chem.		> 250	> 20	G	G	G	2.23	1.45			8.50	.4132	.2768	.2975
Ethylene/tetrafluoroethylene	Tefzel 280	Du Pont		> 250	16-20	G	G	G	1.80	1.40	1.70	3-4	9 [illegible]	.5213	.3493	.3753
Hexafluoropropylene vinylidene fluoride	Viton AHV	Du Pont		> 250	4-5	G	P	P	(e)	1.37	1.88		10.00	.7234	.4847	.5208
Silicone	Sylgard 184	Dow	Yes		10-20	G	G	F	(f)	1.43	1.05	4-5	9.02	.3419	.2287	.2462
Silicone	RTV 615	G.E.	Yes		10-20	G	G	F	(g)	1.43	1.05	4-5	8.84	.3351	.2242	.2413
Perfluoroalkoxy	PFA 9705	Du Pont		> 250	> 20	G	G	G	0.53	1.35	2.15		11.00	.8536	.5719	.6146
Silicone "glass resin"	Resin 650	Owens-Illinois	Yes		16-20	G	G	G		1.45			15.00	.7040	.4709	.5069
Chlorotrifluoroethylene	Resin 61	3M		> 250	> 20	G	G	G	1.72	1.38	2.1	3-4	20.00	1.516	1.014	1.092
Chlorotrifluoroethylene/vinylidene fluoride	Kel-F 800	3M		> 250	1-5	G	P	G	0.23	1.44	~2.0	3.5	20.00	1.444	.9660	1.040
Polyvinyl fluoride film	Tedlar 20	Du Pont		> 250	10-20	G	G	G	3.60	1.46	1.38	2.8	5.90	.2939	.1966	.2116

(a) Springborn Laboratories educated opinion
(b) No UV absorber
(c) Protected with an internal UV absorber and an external coating or sheet containing a UV absorber.

(d) Gel - special testing required
(e) 103 psi (200%) apparent modulus
(f) 586 psi (100%) apparent modulus
(g) 389 psi (100%) apparent modulus

Code: G = Good; F = Fair; P = Poor

TABLE 13

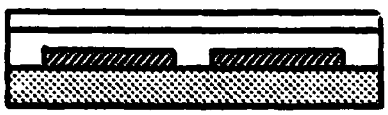
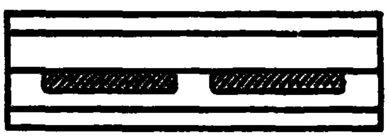
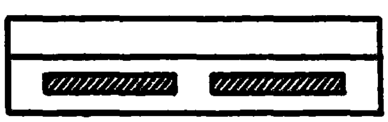
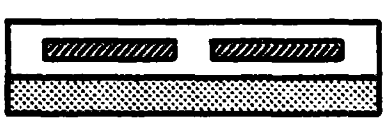
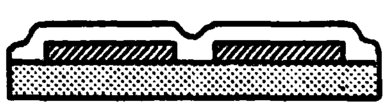
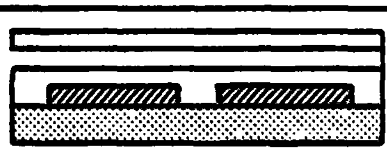
Processable Transparent Polymers

Polymer	Cost ($/Lb)	Upgrading Potential in Years	
		10	20
• Casting Polymers			
Silicone - Sylgard 184	11	G	G
- Q36527	9	G	G
Aliphatic urethane	(a)	G	F
Acrylics	1.50-1.65	G	G
Hot melts -			
Ethylene/vinyl acetate	0.80-0.90	G	F
Acrylic	1.50-3.00	G	G
Polyvinyl chloride copolymer plastisol	0.50-0.60	G	F
Flexibilized polyester	0.38	G	F
• Solid Polymers Fabricable Below 250°F			
Polyvinyl butyral	1.50	G	F
Acrylic copolymer	1.30	G	G
Ionomer	0.64	F-G	P-F
Ethylene/vinyl acetate	0.50	G	F
Ethylene/ethyl acrylate	0.48	G	F
Plasticized polyvinyl chloride copolymer	0.30-0.40	G	F

(a) Price is expected to be between $1.00 and $4.00/pound.

FIGURE 2

Flat-Plate Solar Module Design

Design	No.	Description
	1.	Cells bonded to rigid substrate; transparent encapsulant, top cover.
	2.	Cells bonded to underside of transparent superstrate/top cover; encapsulant; back cover.
	3.	Rigid single transparent encapsulant; top cover.
	4.	Flexible single transparent encapsulant; rigid clear superstrate.
	5.	Flexible single transparent encapsulant; rigid substrate.
	6.	Cells bonded to rigid substrate; clear conformal top coat.
	7.	Cells bonded to clear superstrate/top cover; conformal under coat.
	8.	Cells bonded to rigid substrate; clear encapsulant; air gap; top cover.
	9.	Cells bonded to rigid substrate; air gap; top cover.

6. CONCLUSIONS AND RECOMMENDATIONS

1. The plasma spray process has not been successful on the trial module encapsulations attempted so far. Cell fracturing and solder melting have been the predominant modes of failure. The process is in its infancy, however, and does demonstrate the potential to be of use in future phases of the LSSA project.

2. The ability to formulate ultraviolet screening coatings of low cost has been demonstrated. Using solution acrylic polymers (Rohm & Haas, Acryloid series) as vehicles, coatings of one mil thickness were found to have low, and in several cases zero, percent transmittance in the range from 290-350 nm. The cost of these coatings was in the order of $0.01 per square foot per mil.

3. The results of material testing after the first EMMAQUA exposure (4-month) have been obtained. The data shows very similar trends in optical properties to the 240-day exposures to Weather-Ometer and RS-4 fluorescent sunlamp conditions. This and other EMMAQUA data will hopefully yield a more definite correlation of natural and artificial weathering conditions in the future.

4. Coefficients of linear thermal expansion were measured for thirteen polymers and found to be eight to sixty times that of silicon. Thermal cycling will obviously cause stresses to form at any polymer/cell interface. The encapsulant material must therefore be of sufficiently low modulus to accommodate expansion differentials.

5. The flat-plate module construction is assumed to be the most efficient collector surface. Based on this assumption, nine basic variations in design were considered from which six construction elements could be identified. This permits selection of materials for use as specific elements and introduces a much broader range of possibilities.

6. Surveys are being conducted to identify the most appropriate materials for each construction element:

   (a) Outer covers (coatings)

   (b) Superstrates

   (c) Pottants

   (d) Substrates

   (e) Back covers (undercoats)

   (f) Adhesion

7. The lowest cost substrate materials found so far have been chip board and plywood, at \$0.041-\$0.044 per square foot (normalized to 0.1 inch thickness).

8. The most inherently weatherable materials found to date are fluorocarbons, silicones, glass, and acrylics. Acrylics are the only weatherable polymers showing potential for ready processing and low cost. Materials surveys will consequently emphasize them.

7. FUTURE WORK

Efforts during the next quarter will emphasize the following activities:

1. Trial encapsulation of miniature solar cell modules with a compound optimized for the plasma spray process to further investigate the feasibility of this method.
2. Further investigation into low-cost ultraviolet screening coatings using silicones and acrylic vehicles.
3. Determination of the efficiency of the UV screen coatings prepared to date by examination of their ability to protect unstable polypropylene.
4. The preparation of functional Saflex (plasticized PVB) and glass laminated solar cells for inclusion into the encapsulation testing program.
5. Measurement and correlation of I/V characteristics of cell modules recently completing EMMAQUA exposure.
6. Continuing surveys of materials to fit each of the six identified material construction elements.
7. An emphasized study of commercially available acrylics as pottants, adhesives, coatings, and load-bearing materials.